Contents

Topic 10 - Principles of Bioenergetics

Dynamic steady state

Living organisms exist in a dynamic steady state, macromolecules are constantly being degraded and resynthesised.

Maintaining a dynamic steady state requires energy

Living cells require energy for:

- Synthesis of new macromolecules / chemical bonds
- Transport molecules against concentration gradient
- Mechanical work
- Maintenance of body temperature

Cells obtain energy by extracting it from energy rich compounds such as glucose, protein and fatty acids.

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{yeilds} 6CO_2 + 6H_2O + energy$$

Metabolism

Metabolism is the sum of ALL biochemical reactions occurring within the cell

- **Catabolic** - energy-liberating reactions (exergonic)
  - The products have less energy than the reactants, therefore change in energy (ΔG) is –ve
  - e.g., oxidation of glucose, fatty acid
  - These reactions are usually **spontaneous**
  - Energy is conserved in ATP and reduced electron carriers (NADH, $FADH_2$)
- **Anabolic** - energy-requiring reactions (endergonic)
  - The products have more energy than the reactants, therefore ΔG is +ve
  - e.g., synthesis of proteins, TAG, glycogen
  - **Will not occur spontaneously**
  - Require input of energy (ATP) and reducing power (NADH, $FADH_2$)

To carry out thermodynamically unfavourable (endergonic reactions), they must be **coupled to exergonic reactions**, so the overall process has a negative free energy change, to occur spontaneously in the cell

Anabolic and catabolic pathways need to be regulated to prevent simultaneous synthesis and degradation which is wasteful. This occurs through a process called **reciprocal regulation**, the activation of one pathway suppresses the opposite pathway

Metabolic control mechanisms

- **Control of intracellular substrate concentration** – the concentration (or availability) of substrates affects the rate of a reaction
- **Control of allosteric enzymes by inhibitors and activators** - some of the enzymes in a metabolic pathway are regulatory enzymes, the rate of these enzymes control the rate of the whole pathway. Allosteric enzymes respond to key inhibitors and activators, their activity can be inhibited or activated by the level of product or other chemical.
    - *Feedback inhibition* is the phenomenon where the output of a process is used as an input to control the behaviour of the process itself, oftentimes limiting the production of more product.
- **Control of amount of enzymes** - by regulating the rate of synthesis of these proteins
- **Control of enzymes through signalling substances** - enzymes can be inactivated or activated by phosphorylation

Classes of biochemical reactions

- Group transfer reactions
- Oxidation-reduction
- C-C cleavage
- Internal rearrangements, isomerisation, elimination
- Free radical reactions

Bioenergetics and thermodynamics

1st Law of Thermodynamics

- The total amount of energy in the universe remains constant. It cannot be created or destroyed
- Energy can only be changed or transported from one region to another

2nd Law of Thermodynamics

- In all natural processes, the entropy (disorder) of the universe increases

Gibbs free energy G, and Gibbs free energy change ΔG is the amount of energy available during a reaction, this determines whether reactions are spontaneous

When ΔG is negative:

- Reaction releases energy
- Reaction is exergonic
- Reaction is thermodynamically favourable
- can proceed in the absence of energy provided from outside the system – spontaneous

When ΔG is positive:

- Reaction requires energy
- Reaction is endergonic
- the process is thermodynamically unfavourable
- energy must be supplied from outside the system to make the overall free energy change negative

When ΔG is equal to zero:

- the reaction is at equilibrium

Standard Free Energy Change ΔG° - free energy change of a reaction under standard conditions:

- T = 298 K (25°C)
- 1 atmosphere
- Initial concentration of reactants and products is 1 M

Biological standard free energy change ΔG'°

- Same conditions as above but [H+] = 10-7M (pH 7.0) and [H2O] = 55.5 M
- For reactions that involve Mg2+, the [Mg2+] = 1 mM

For the reaction: $A + B \Leftrightarrow C + D$

The equilibrium constant is: $K_{eq} = \frac{[C]\times[D]}{[A]\times[B]}$

The standard free energy change (ΔG°) is related to the equilibrium constant by the equation:

$$\Delta G^{\circ} = -RT \ln K_{eq}$$

- R = gas constant = 8.315 J/mol.K (J.mol-1.K-1)
- T = absolute temperature (K)

In cells, ΔG not ΔG° determines reaction direction because cells don't have 1 M concentrations of each of the reactants and products.

$$\Delta G = \Delta G^{\circ} + RT \ln \frac{[C] \times [D]}{[A] \times [B]}$$

Phosphoryl group transfers and ATP

Cells oxidise glucose in many steps, and trapping the released energy in small, useable forms of energy as apposed to combustion which is one big unstable and unusable release of heat.

ATP is the common chemical store of energy, it can be coupled to endergonic reactions to make them spontaneous. The majority of the energy in ATP is **stored in the first two phosphoanhydride bonds**, the third bond is a phosphor-ester bond, this is not generally used in biology.

- The hydrolysis of ATP to ADP occurs in **3 steps** and yields **-30.5kj/mol** in the reaction: $ATP \xrightarrow{yields} ADP + P_i$
- The hydrolysis of ADP to AMP yields **-32.8kj/mol** in the reaction: $ADP \xrightarrow{yields} AMP + P_i$ The
- Hydrolysis of AMP yields only **-12kj/mol**

ATP is not the only phosphate compound found in cells, it is just used as an example of the general reaction. The biological standard free energy change for the transfer of phosphate varies widely for different R groups

Compounds with a lower ΔG° than ATP have a tendency to transfer phosphate to ADP and form ATP

ATP can donate its phosphate to compounds with a lower ΔG°, overcoming equilibria which would otherwise be unfavourable.

Biological oxidation-reduction reactions

Redox Reactions are the most common biochemical reaction in metabolism. It involves the transfer of electrons.

- **Oxidation:** loss of H atoms on C; gain of O atoms on C; releases energy
- **Reduction:** gain of H atoms on C; loss of O atoms on C; incorporates energy

Reduction potential (E) of a reducing agent is a measure of its affinity for electrons (and therefore to become reduced). Positive ΔE values occur spontaneously

The energy made available from redox reactions can be calculated using the equation:

$$\Delta G = -nF\Delta E$$

$$\Delta G^\circ = -nF\Delta E^\circ$$

Where, n = the number of electrons transferred
F = the Faraday constant (96 480 J/V.mol)

!!Both would be given in an exam!!